New Physics Searches in Heavy Flavours

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European Union
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OPERATIONAL PROGRAMME
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MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS, CULTURE & SPORTS
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New Physics Searches in Heavy Flavours

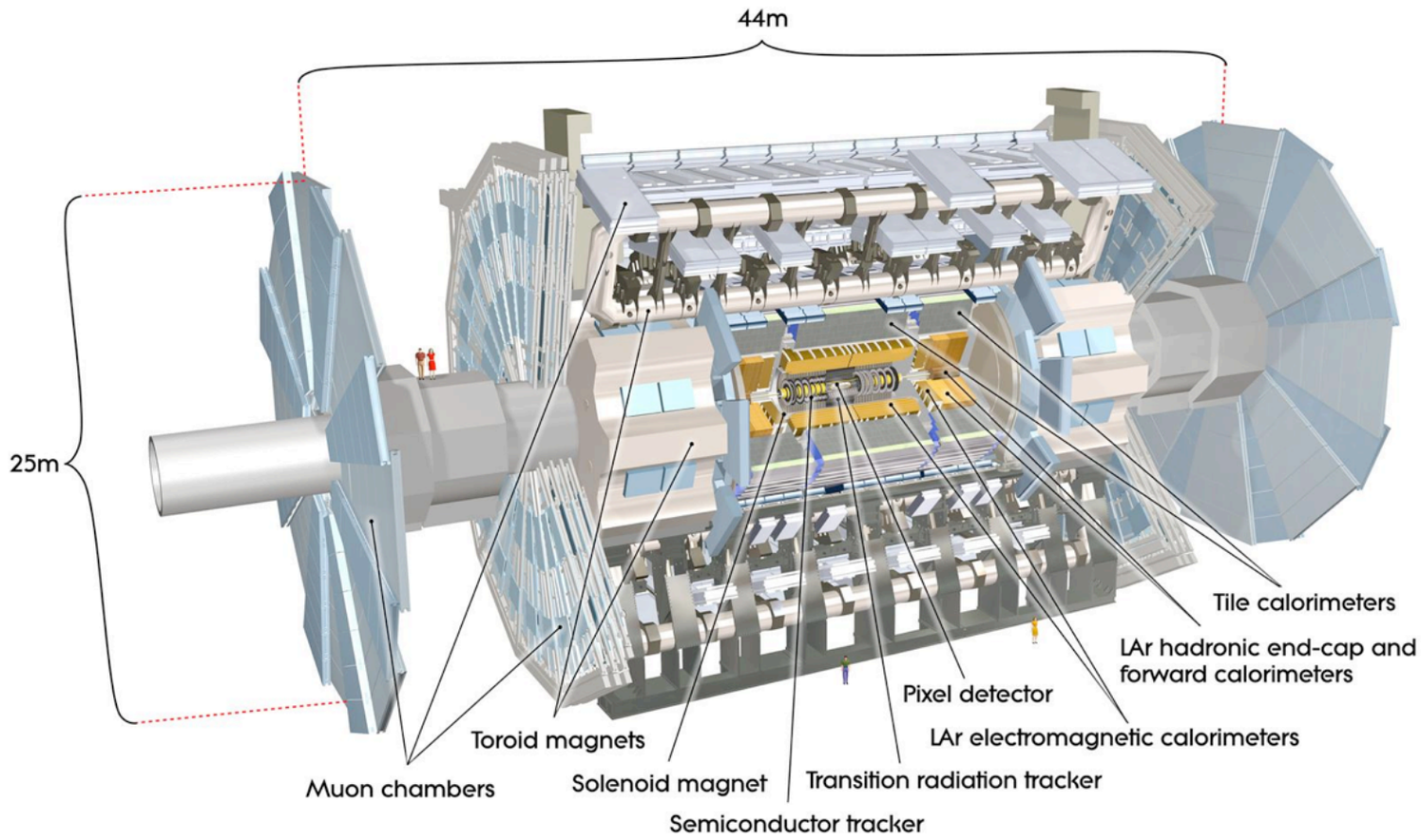
Outline

- The ATLAS detector
- New physics searches in heavy flavours
  - CP violation in $B_s \rightarrow J/\psi\phi$
  - $B_d \rightarrow K^{0*}\mu\mu$ forward-backward asymmetry
- Future plans - Perspectives
- Conclusions

New Physics Searches in Heavy Flavours

The ATLAS detector

- General purpose detector at the LHC
  - Tracking
    - Silicon (Pixel+SemiConductor Tracker) and Transition Radiation Tracker
    - 2 T solenoidal field
- Muon identification:
  - Dedicated tracking chambers
  - 0.5-2T toroidal field



- Tracking
  - 10μm Impact Parameter resolution
    - $\sigma p_T/p_T \sim 0.05\% p_T$ (+) 1.5%
    - $\sigma_m(J/\psi\text{-}\Upsilon) \sim 60\text{-}120$MeV (ID dominated)

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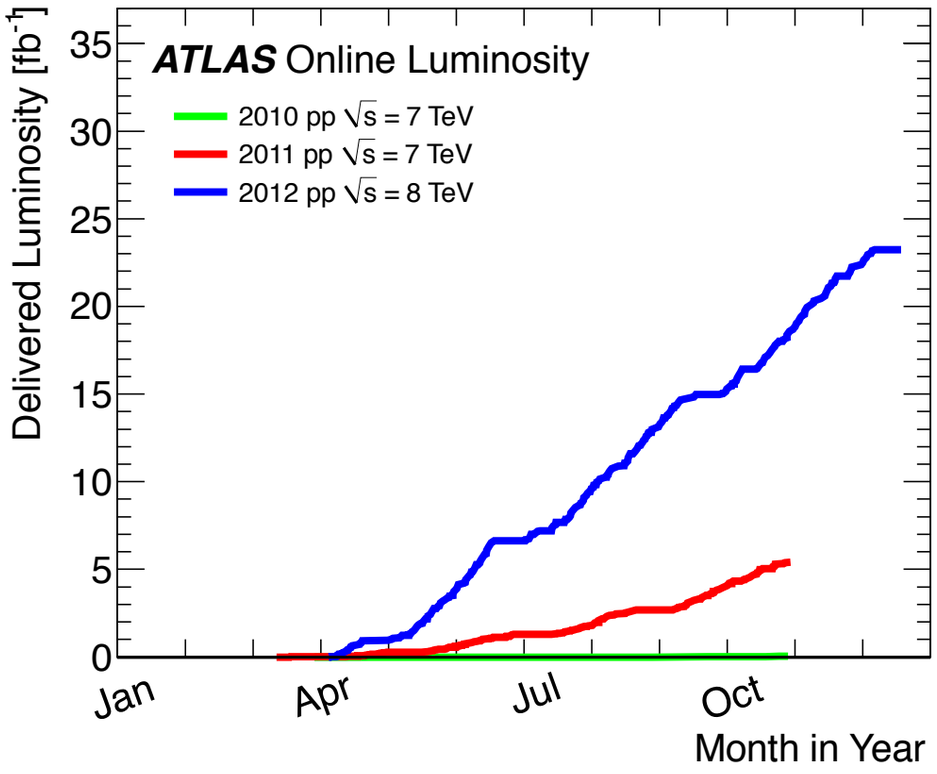
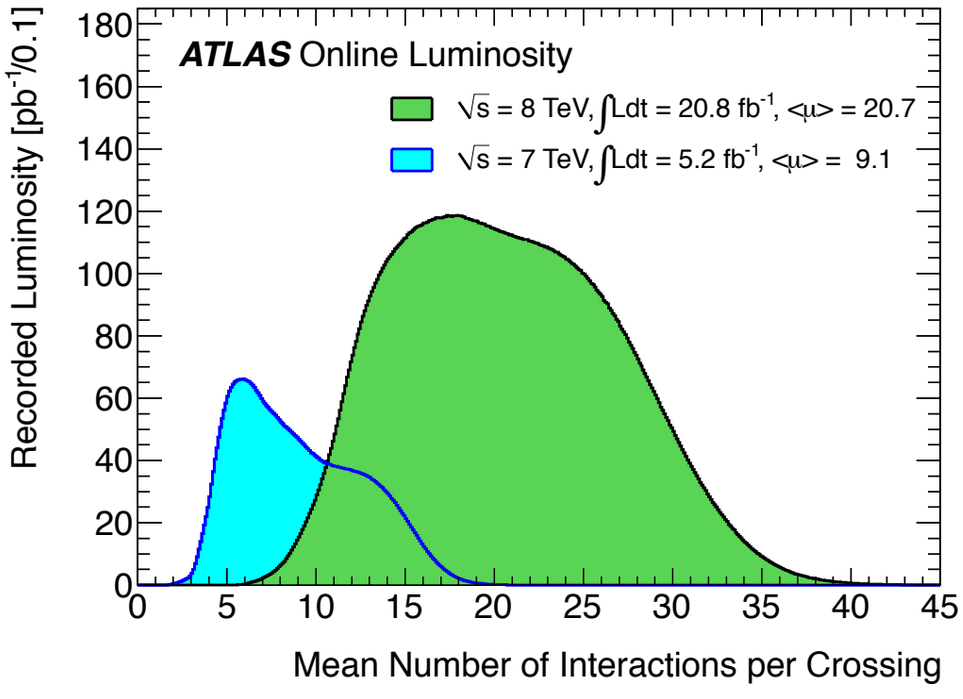
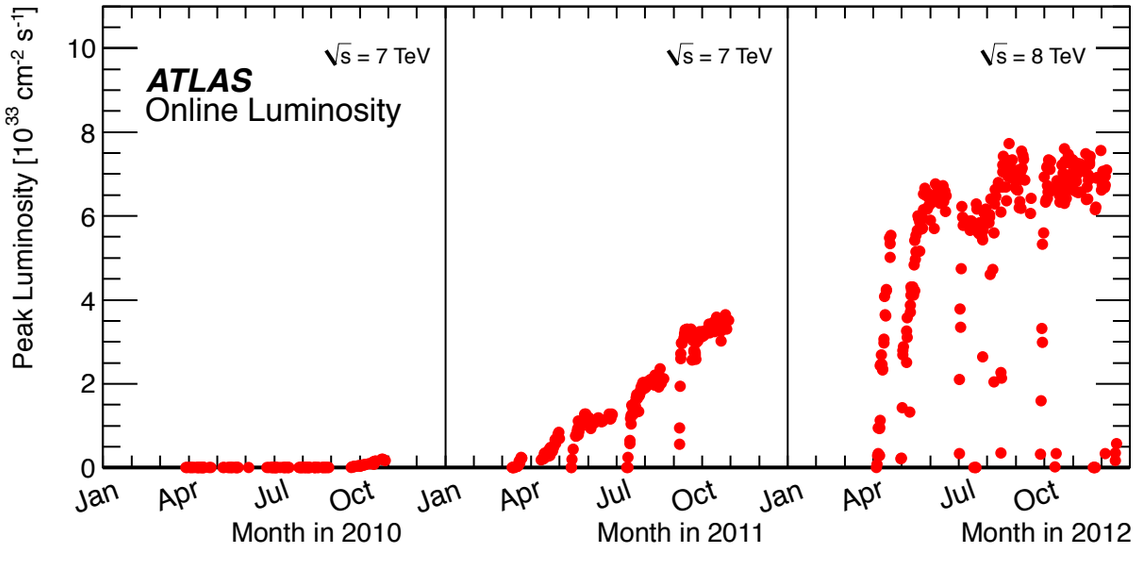
ATLAS data taking

- 2011
  - More than 5 fb^{-1} recorded
- 2012
  - ~23 fb^{-1} recorded
  - Flatter instantaneous luminosity profile
  - Harsher pile-up conditions!





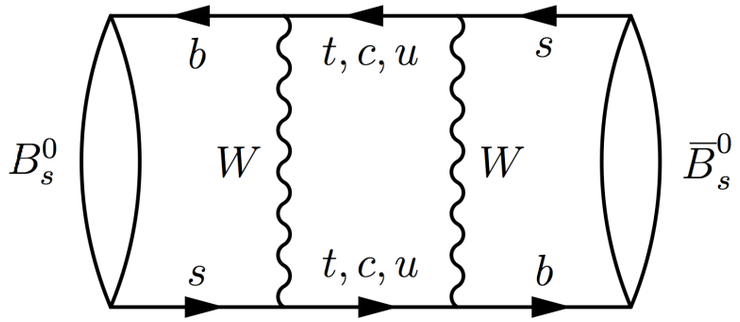


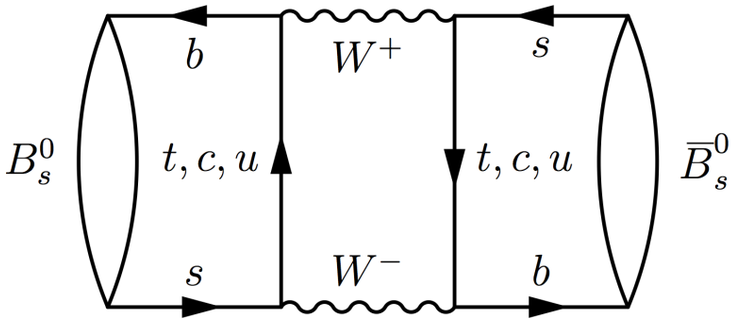
New Physics Searches in Heavy Flavours

Where new physics could hide?

ATLAS-CONF-2013-039

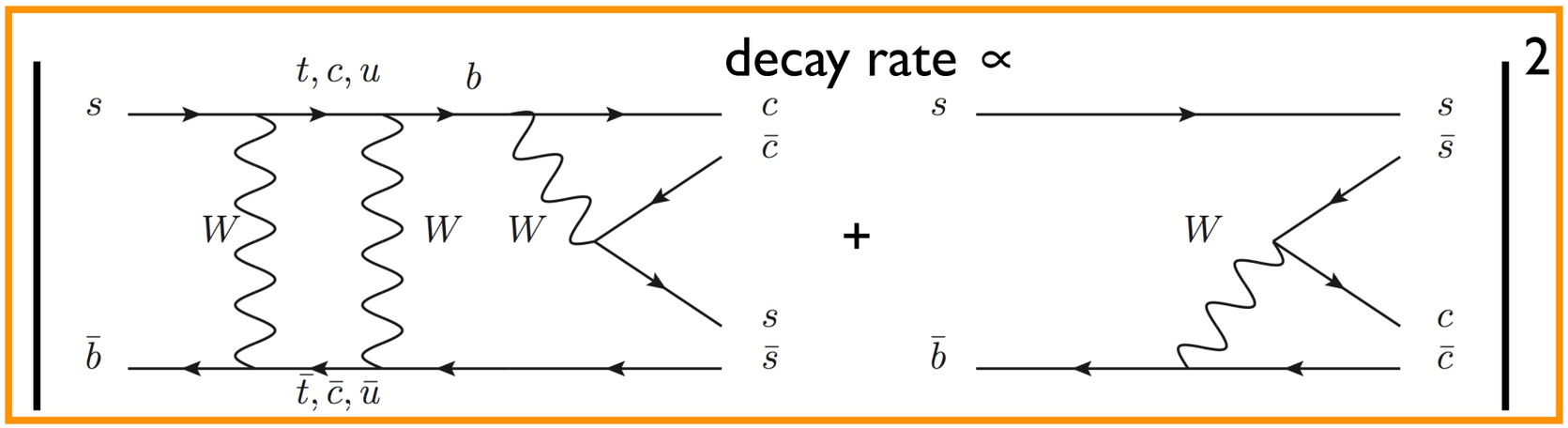
- B_s mesons have two mass eigenstates B_L and B_H





- CP-violation in interference between direct decay and mixing mediated:
  $B_s \to J/\psi(\mu\mu)\phi(KK)$

- The final state is self-conjugate and to decompose the decay into CP-odd and CP-even components one must perform an angular analysis on the decay products



Analysis updated including flavour tagging

previous analysis: JHEP 12 (2012) 072

Decay parameters:

Γ_s, $\Delta\Gamma_s$: average width and width difference of the two eigenstates

ϕ_s: phase arising from mixing-induced CP-violation

$|A_\perp|$, $|A_{||}|$, $|A_0|$: CP eigenstate amplitudes of which the final state is an admixture

$\delta_\perp$, $\delta_{||}$, δ_0: Phases of the above

$|A_s|$, δ_s: S-wave components

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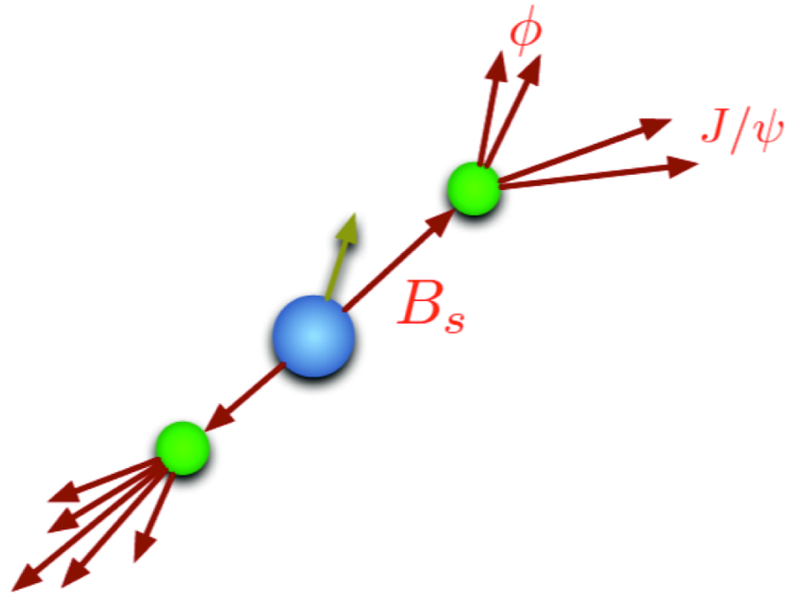
Flavour tagging

ATLAS-CONF-2013-039

- B_s flavour at production from the other B in the event (Opposite-Side Tagging - OST)
  - Identification of $B_s - \overline{B_s}$

$$Q = \frac{\sum_i^{\mathrm{N_{trk}}} q^i \cdot (p_T^i)^\kappa}{\sum_i^{\mathrm{N_{trk}}} (p_T^i)^\kappa}$$

- Increases sensitivity to ϕ_s without changing the sensitivity on $\Delta\Gamma_s$
- How is it performed?
  - Taggers are calibrated with self-tagging process $B^\pm \to J/\psi K^\pm$
  - Two taggers
    - Muon cone charge tagger - Cone created about a muon track
    - Jet charge tagger - Used in the absence of a muon
- Run for each signal candidate and inserted into the fit as a probability for $B_s - \overline{B_s}$



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Flavour tagging

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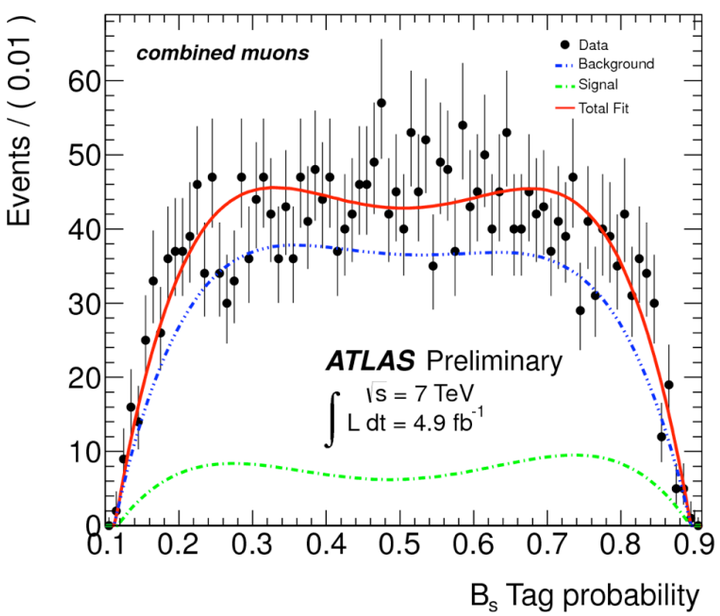
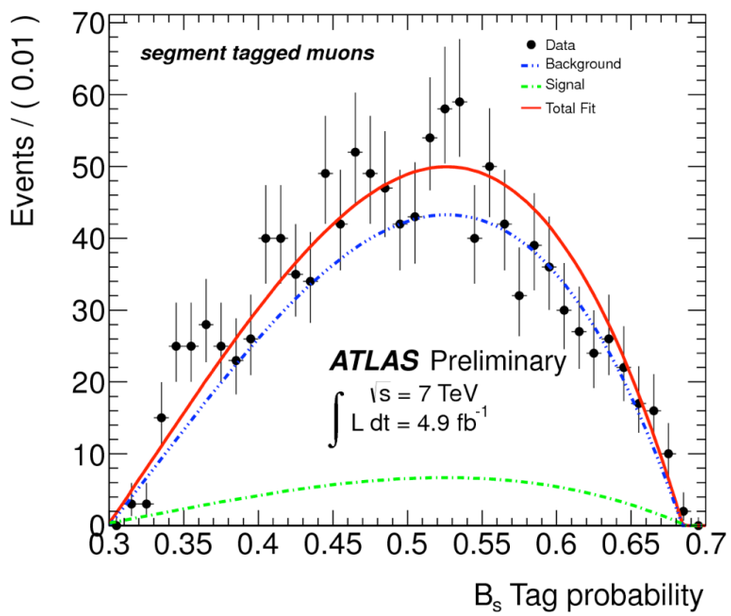
- Efficiency ε: fraction of successfully tagged candidates
- Dilution D: 1-2w
  - w: wrong-tag fraction
- Tagging power: $\varepsilon D^2 = \sum_i \varepsilon_i D_i^2$

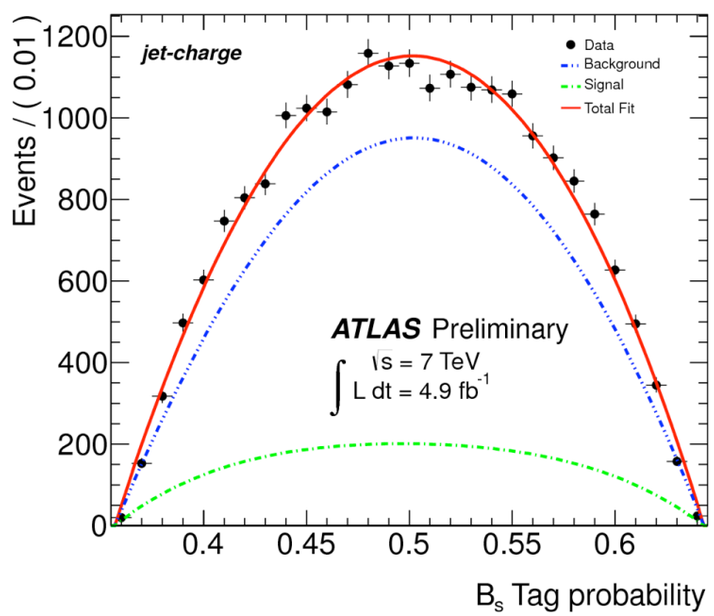
Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Segment Tagged muon	1.08 ± 0.02	36.7 ± 0.7	0.15 ± 0.02
Combined muon	3.37 ± 0.04	50.6 ± 0.5	0.86 ± 0.04
Jet charge	27.7 ± 0.1	12.68 ± 0.06	0.45 ± 0.03
Total	32.1 ± 0.1	21.3 ± 0.08	1.45 ± 0.05

- Combined Muon – a muon with inner detector and muon spectrometer track information
- Segment Tagged Muon – muons with only muon spectrometer track information

Obtained from data $B^{\pm} \rightarrow J/\psi K^{\pm}$





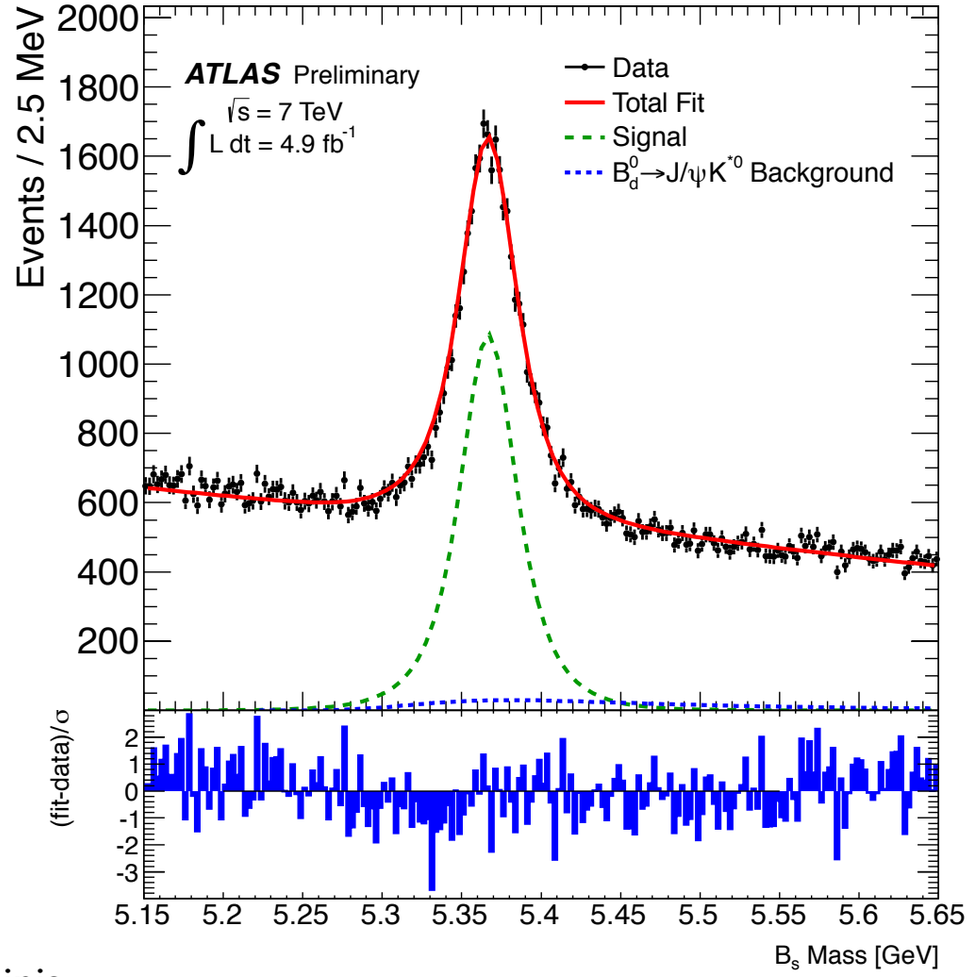


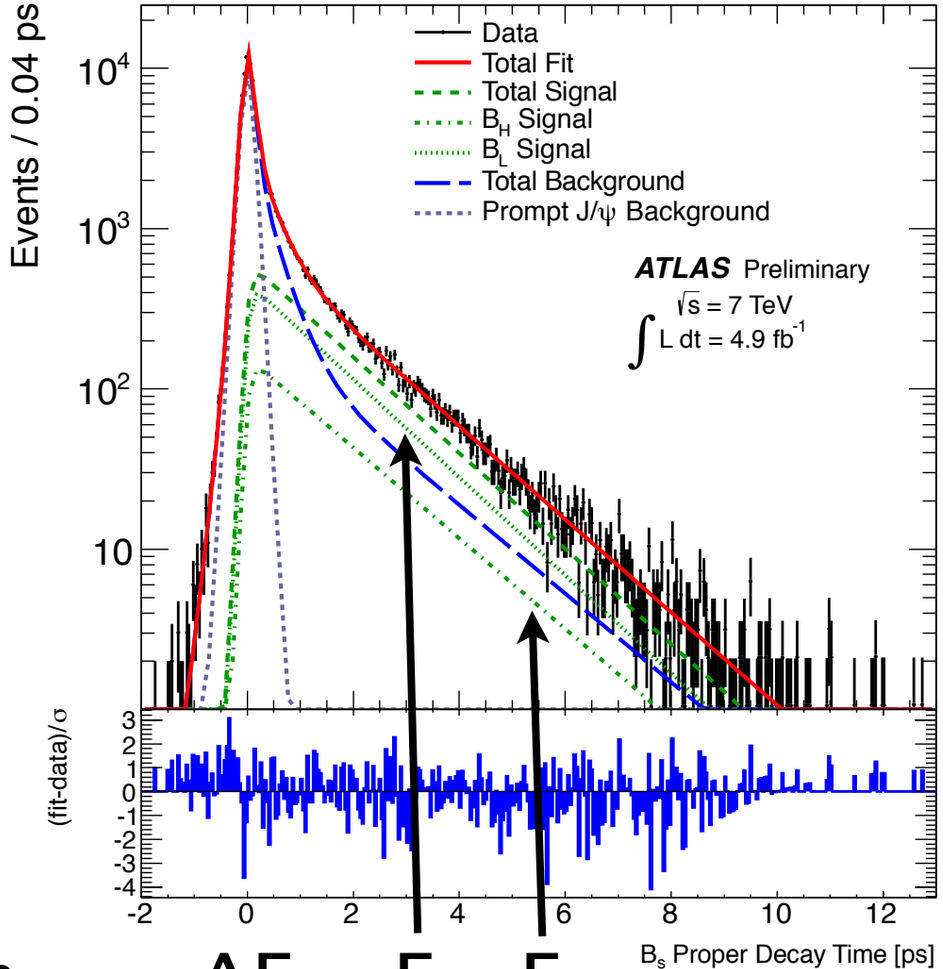
New Physics Searches in Heavy Flavours

Fit results: mass and proper time

ATLAS-CONF-2013-039

- Simultaneous fit to
  - Reconstructed mass & its uncertainty
  - Measured proper decay time & its uncertainty
  - Tag probability
  - Transversity angles $\Omega=(\theta_T, \psi_T, \phi_T)$



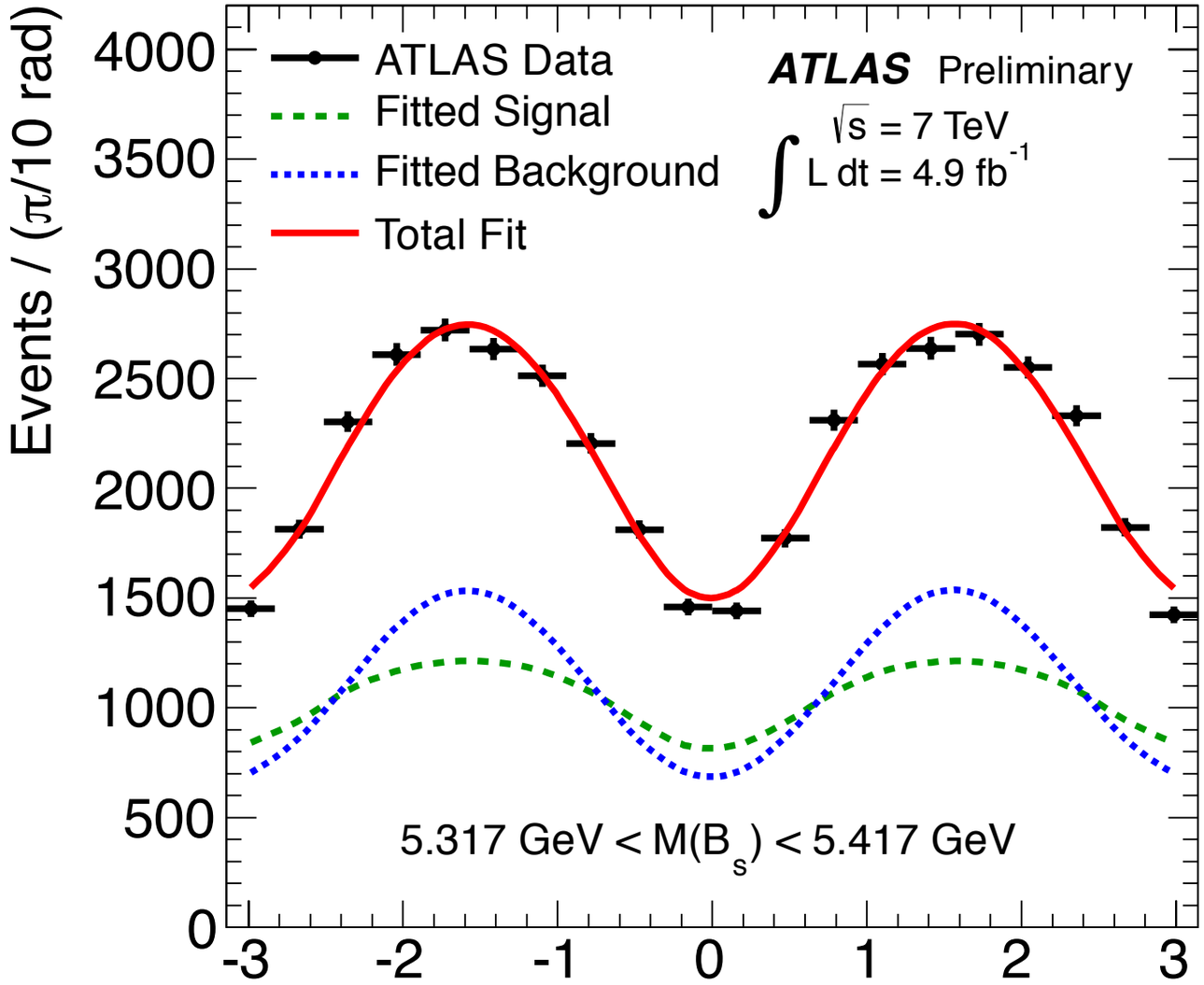


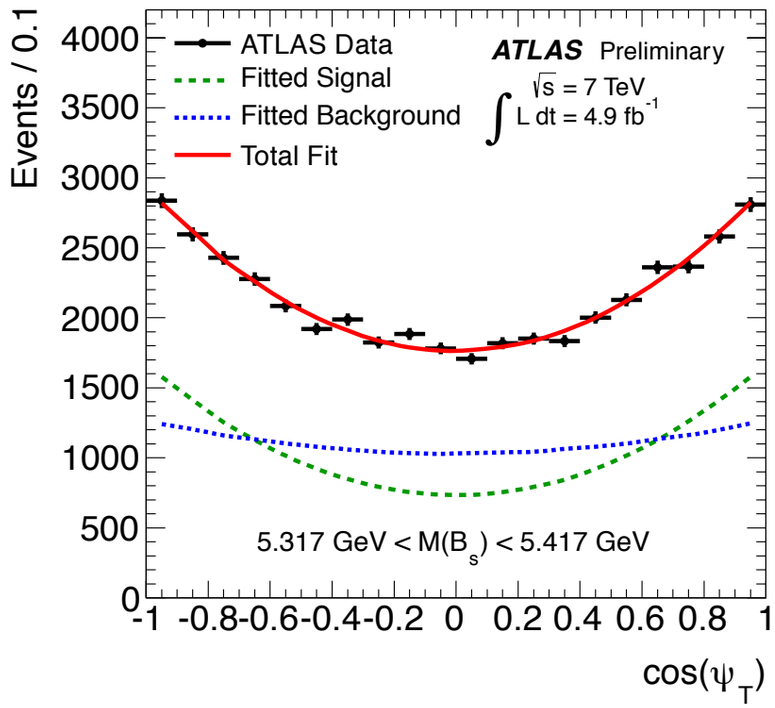
$\Delta\Gamma_s = \Gamma_L - \Gamma_H$

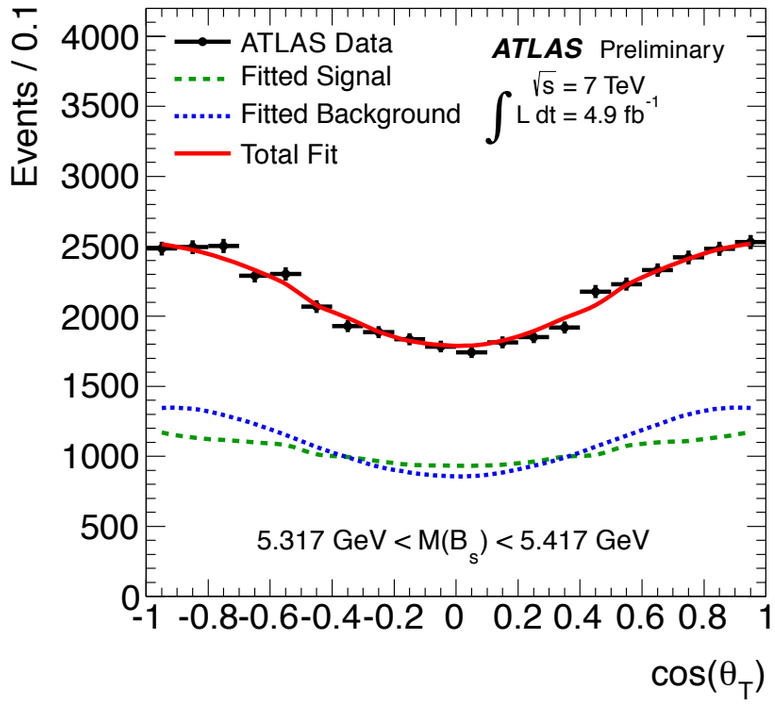
New Physics Searches in Heavy Flavours

Fit results: transversity angles

ATLAS-CONF-2013-039







θ_T, ψ_T, ϕ_T allows to disentangle the amplitudes of the projections on the transversity basis:

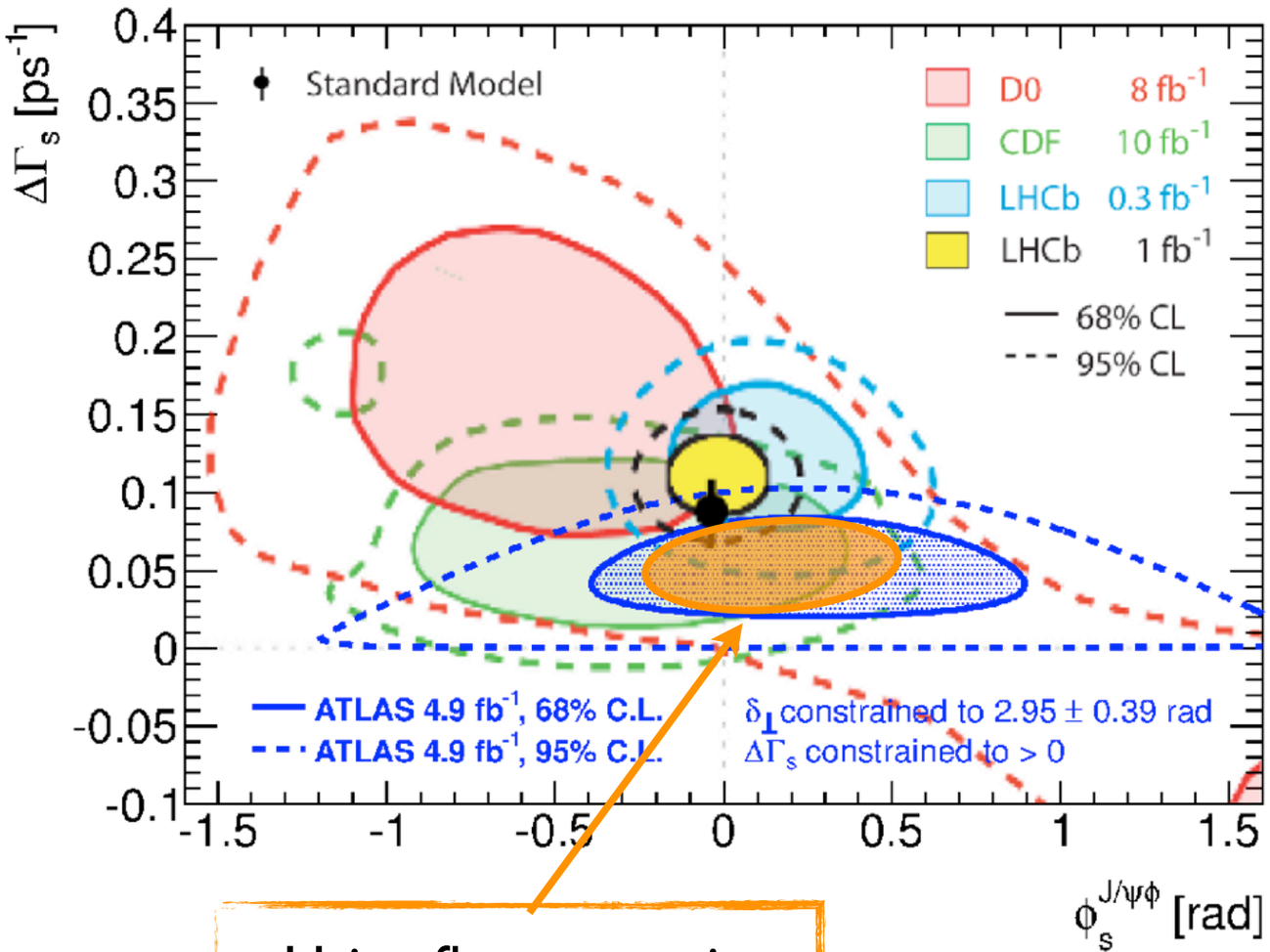
$A_0, A_{||}, A_\perp, A_s$

New Physics Searches in Heavy Flavours

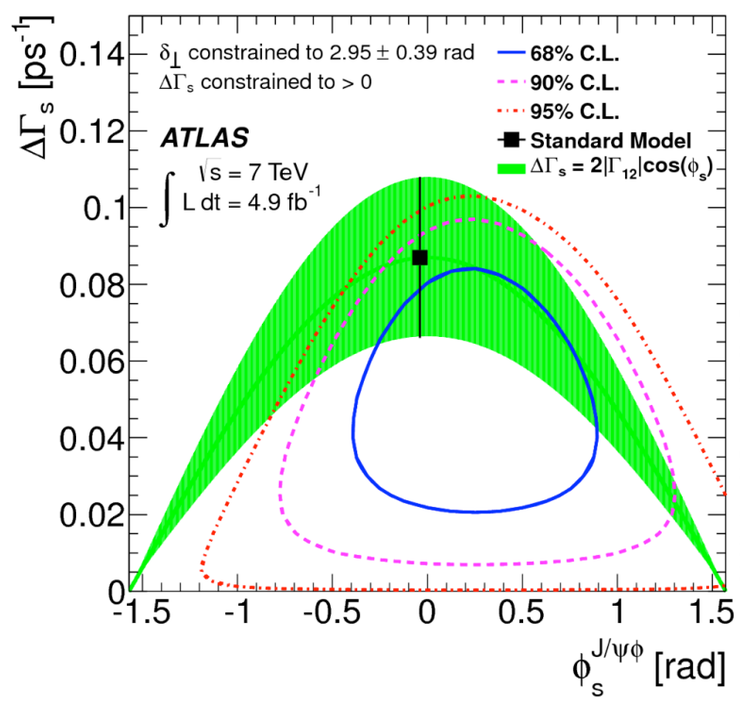
CP violation in $B_s \to J/\psi\phi$ with flavour tagging

ATLAS-CONF-2013-039

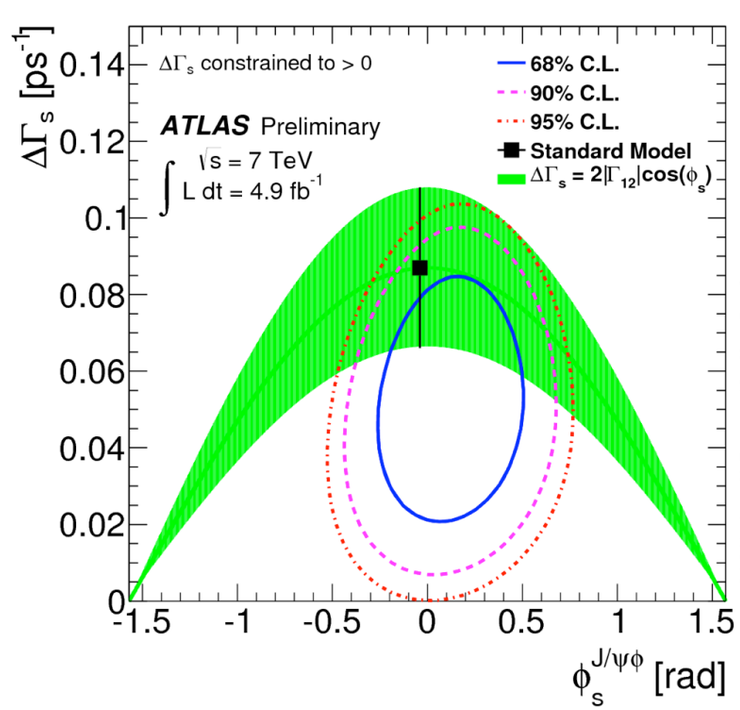
- Uncertainty of ϕ_s improved by 40% compared to untagged analysis
- $\Delta\Gamma_s$ central value and uncertainty unchanged



Using flavour tagging



Previous measurement



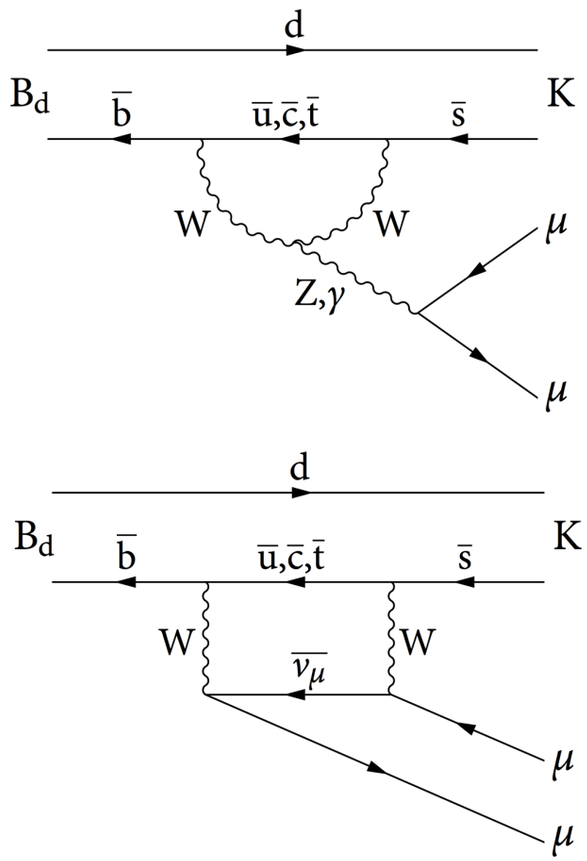
Using flavour tagging

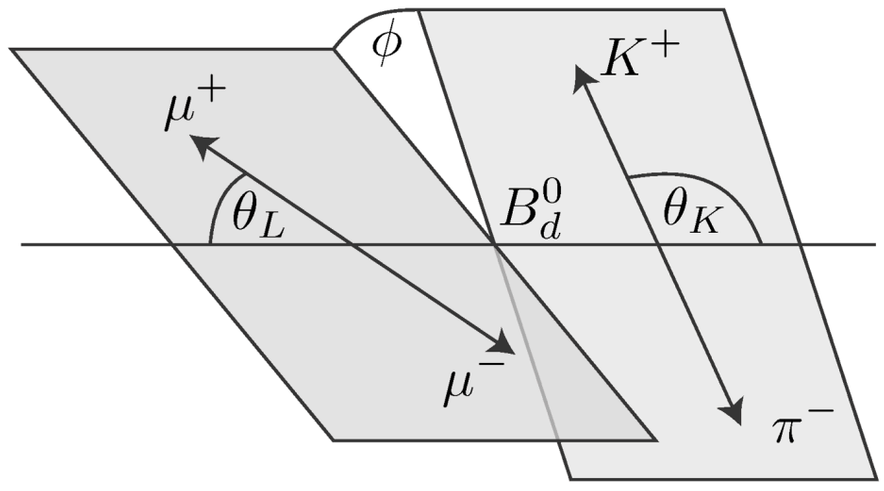
New Physics Searches in Heavy Flavours

$B_d \to K^{0*}\mu\mu$ angular analysis

ATLAS-CONF-2013-038

- Semi rare process
  - Occurs via loops that mediate $b \to s\mu\mu$
  - BR~1.1×10^{-6}
- Angular distribution of the 4 particle final state sensitive to new physics
  - as a result of the interference of new diagrams with the Standard Model diagrams
- Decay described by three angles (θ_L, θ_K, ϕ) and the dimuon mass q^2
- Statistics insufficient for 4 differential distribution
  - 2 out of 3 angles are integrated
- Study the 2-D distributions
  - $d^2\Gamma/dq^2d\cos\theta_L$ and $d^2\Gamma/dq^2d\cos\theta_K$
- Measure
  - K^{0*} longitudinal polarization fraction F_L
  - Lepton forward-backward asymmetry (A_{FB})
  - as a function of q^2



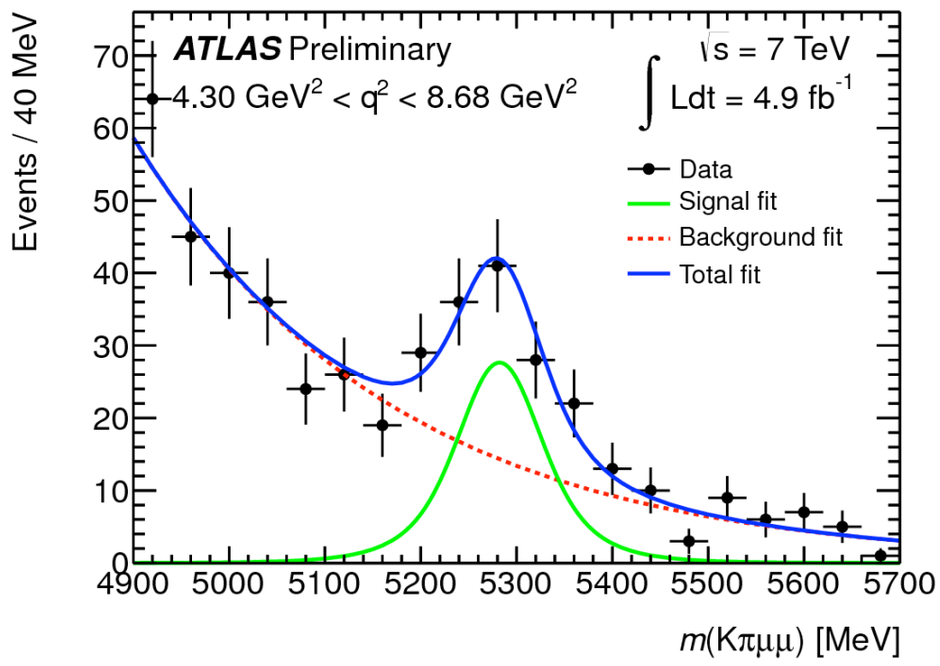


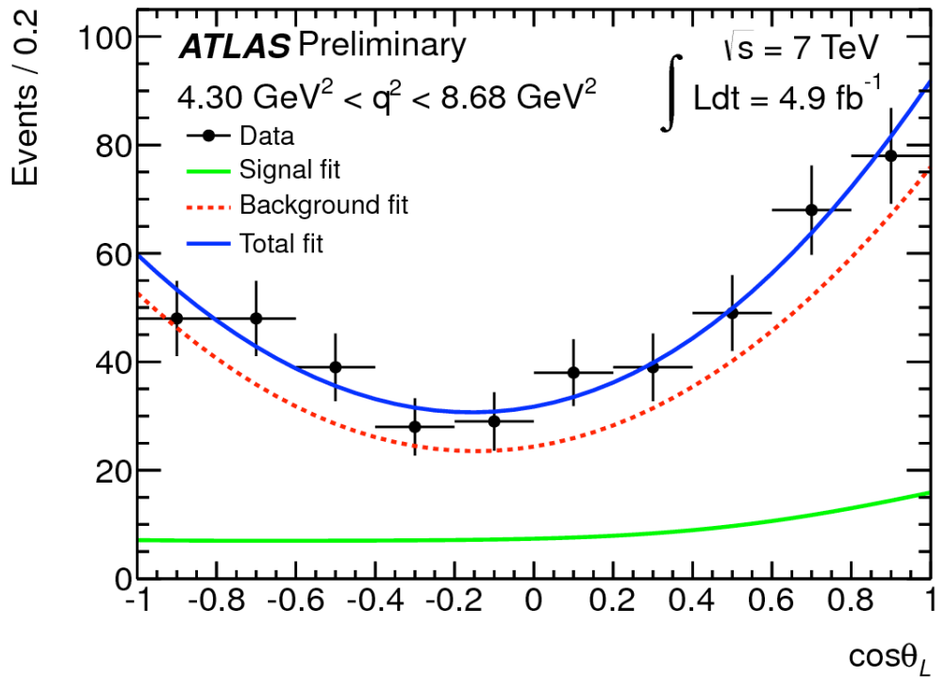
New Physics Searches in Heavy Flavours

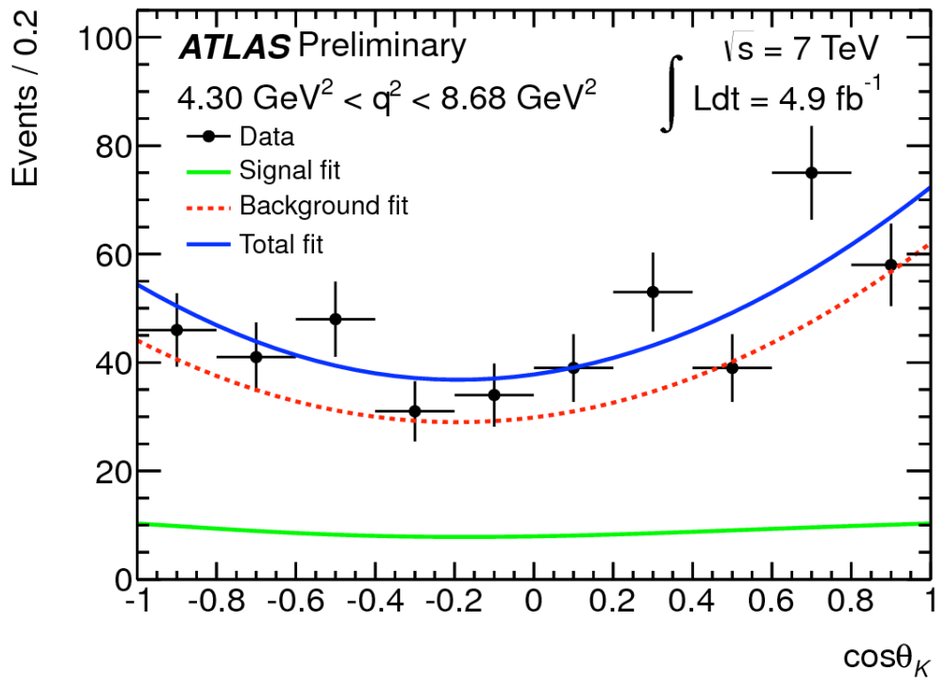
$B_d \to K^{0*}\mu\mu$ angular analysis

ATLAS-CONF-2013-038

- Measurement of A_{FB} and F_L
- Extended unbinned maximum likelihood fit in each q^2 bin
  - $2.00<q^2<4.30$
  - $4.30<q^2<8.68$
  - $10.09<q^2<12.86$
  - $14.18<q^2<16.00$
  - $1.00<q^2<6.00$
- No measurement on
  - Low q^2 , limited statistics due to trigger acceptance
  - $8.68<q^2<10.09$ - J/ψ region
  - $12.86<q^2<14.18$ - $\psi(2S)$ region







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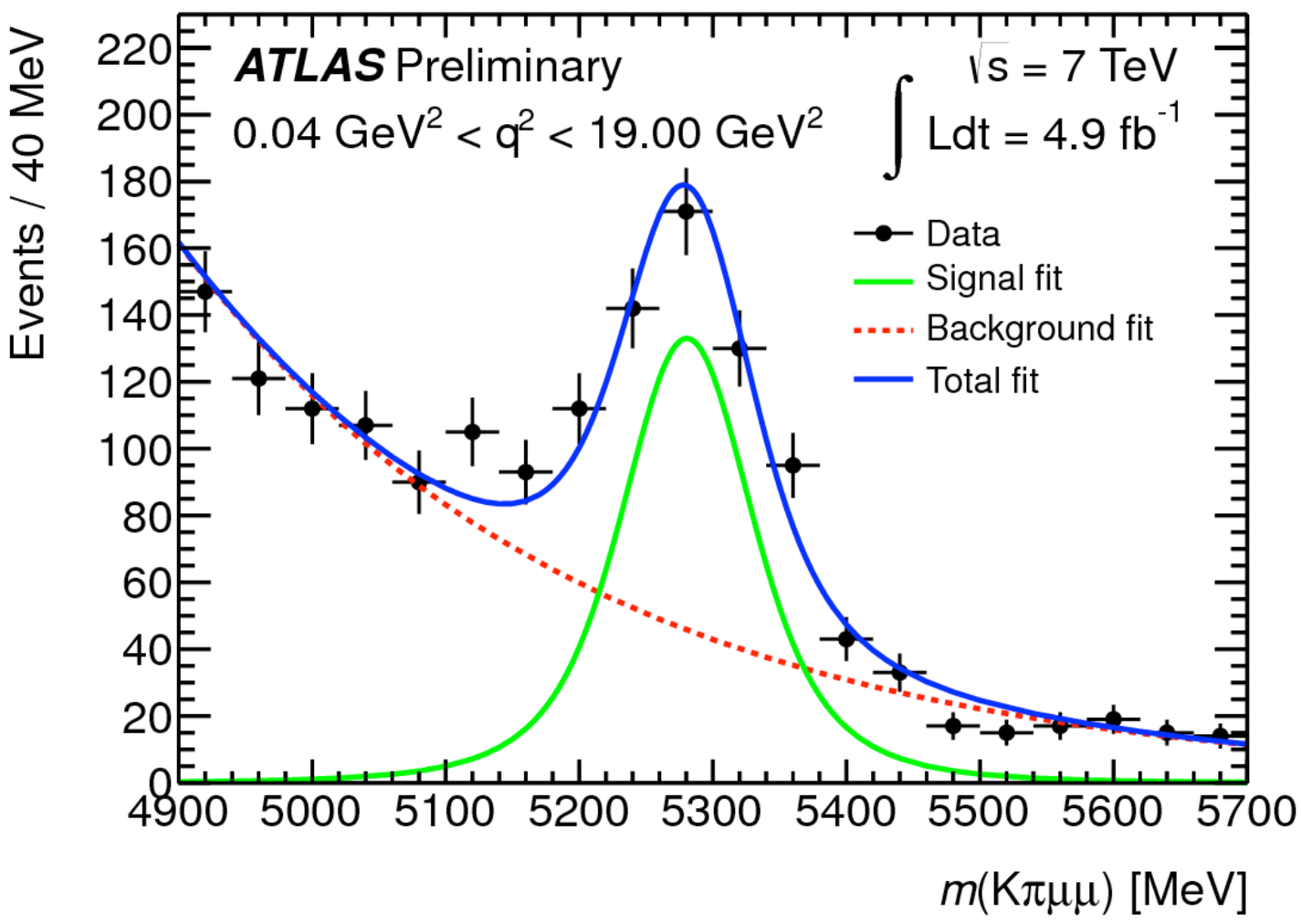
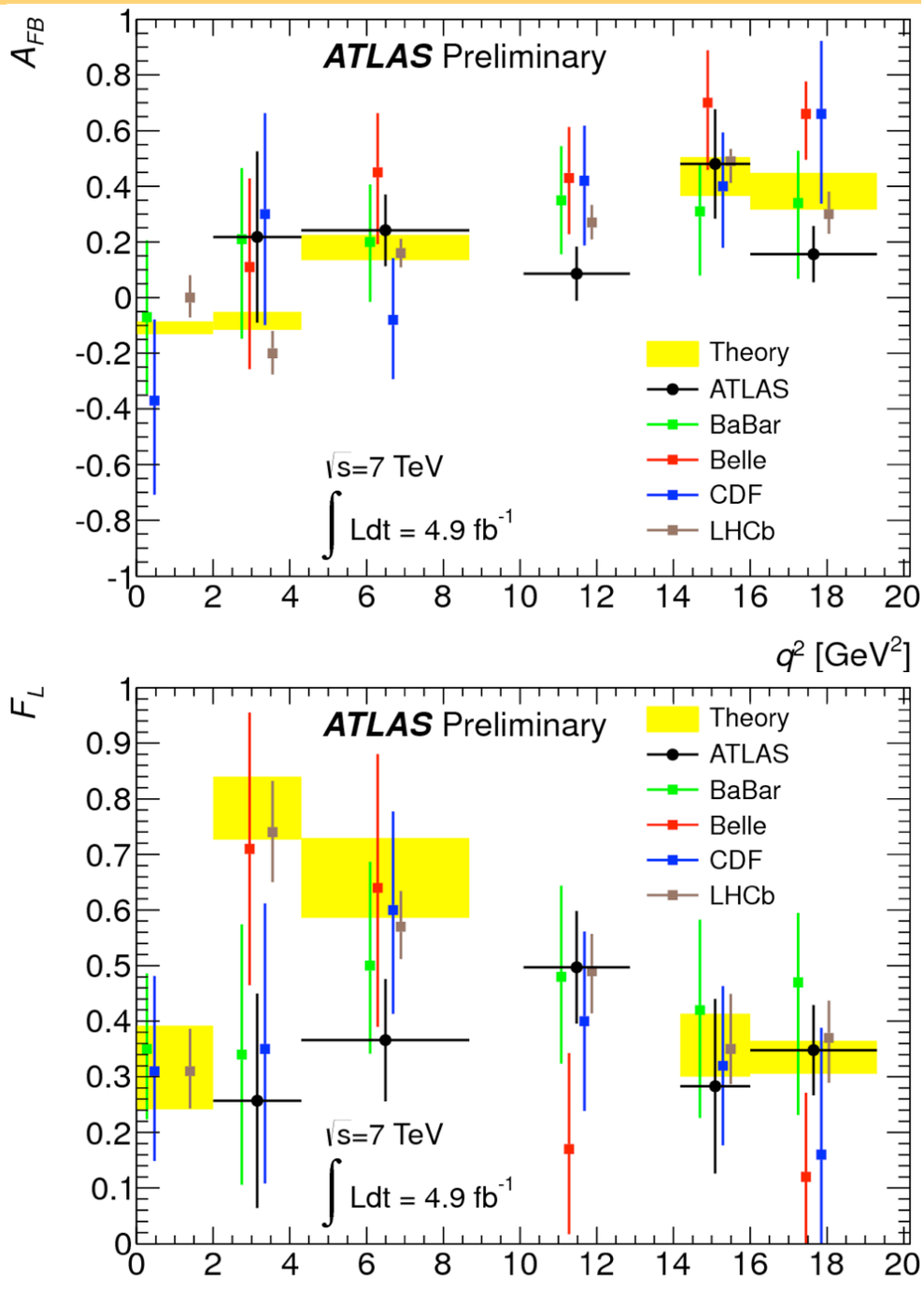
Fit results: mass and proper time

ATLAS-CONF-2013-038





- ATLAS measurement in reasonable agreement with other LHC measurements, although low q^2 distribution needs to be updated with more statistics (only 2011 data used)

Theory: C. Bobeth, G. Hiller and D. van Dyk, arXiv:1105.2659v1

New Physics Searches in Heavy Flavours

Future plans - Perspectives

- $B_d \rightarrow K^{0*} \mu\mu$
  - Measurements of A_{FB} and F_L as a function of q^2
- $B_s \rightarrow J/\psi\phi$
  - Flavour tagged analysis shows a great improvement in precision of physical parameters, without an increase in data
- $B_s \rightarrow \mu\mu$
  - BR($Bs \rightarrow \mu\mu$) upper limit 2.2×10^{-8} at 95% C.L. ($2.4\ fb^{-1}$)
  - Unblinding of full 2011 7TeV data (~$5fb^{-1}$) just done, result under approval
- Results consistent with other experiments
- No significant deviation from Standard Model predictions
- Updated results with higher integrated luminosities and improved analysis techniques under way

$21.7\ fb^{-1}$ more data to analyze

New Physics Searches in Heavy Flavours

Conclusions

- Very successful ATLAS B physics program
  - Consistent data-collection strategy for 2011 and 2012 data taking periods, with good signal collection efficiencies
  - Other ATLAS results
    - Measurement of the Λ_b lifetime and mass - Phys. Rev. D 87 (2013) 032002
    - Inclusive *Y(nS)* differential cross sections and ratios - Phys. Rev. D 87 (2013) 052004
    - Associated production of prompt *J/ψ* mesons and *W* boson in at $\sqrt{s}$ = 7 TeV - ATLAS-CONF-2013-042
    - Production cross section of B^+ at $\sqrt{s}$ = 7 TeV - ATLAS-CONF-2013-008
- Stay tuned

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New Physics Searches in Heavy Flavours

BackUp

New Physics Searches in Heavy Flavours

Summary of systematic uncertainties assigned to parameters of interest

$B_s \to J/\psi\phi$

Systematic Uncertainty	ϕ_s(rad)	$\Delta\Gamma_s(\mathrm{ps}^{-1})$	$\Gamma_s(\mathrm{ps}^{-1})$	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$
Inner Detector alignment	0.04	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Trigger efficiency	< 0.01	< 0.001	0.002	< 0.001	< 0.001	< 0.01
Default fit model	< 0.001	0.006	< 0.001	< 0.001	0.001	< 0.01
Signal mass model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background mass model	0.03	0.001	< 0.001	0.001	< 0.001	< 0.01
Resolution model	0.05	< 0.001	0.001	< 0.001	< 0.001	< 0.01
Background lifetime model	0.02	0.002	< 0.001	< 0.001	< 0.001	< 0.01
Background angles model	0.05	0.007	0.003	0.007	0.008	0.02
B^0 contribution	0.05	< 0.001	< 0.001	< 0.001	0.005	< 0.01
Total	0.10	0.010	0.004	0.007	0.009	0.02

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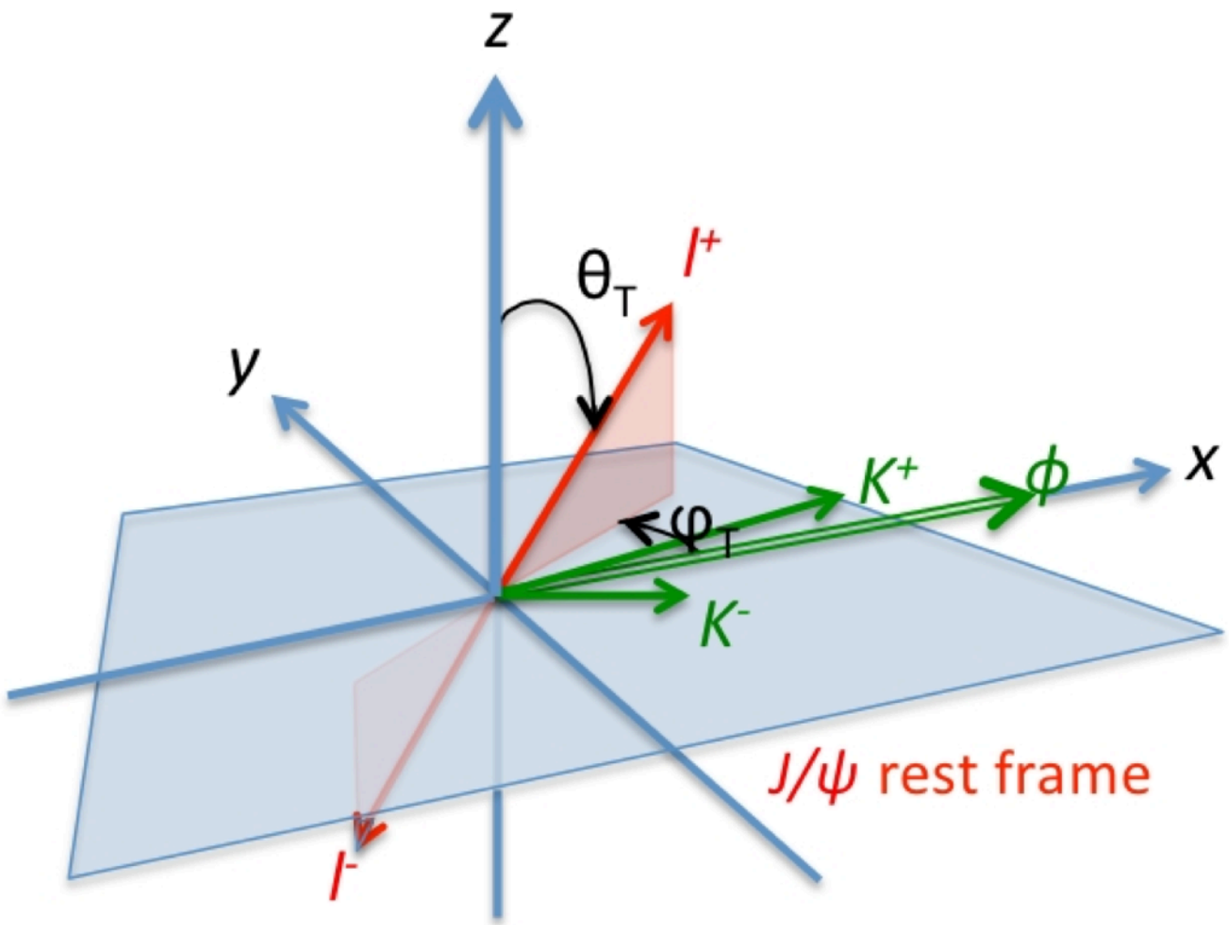
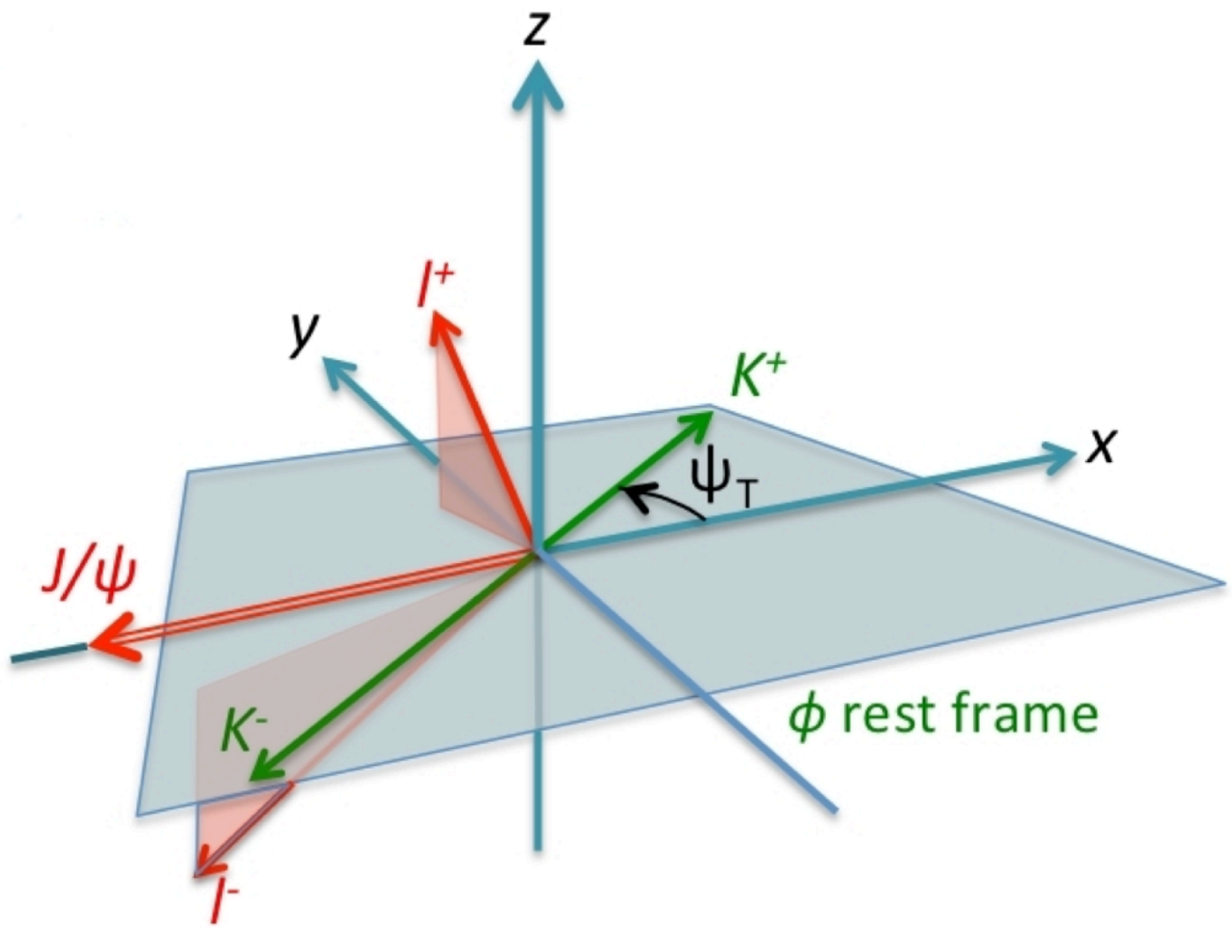
Transversity Basis

$B_s \rightarrow J/\psi\phi$





New Physics Searches in Heavy Flavours

$B_s \to J/\psi\phi$ likelihood fit

$$\ln \mathscr{L} = \sum_{i=1}^{N} \{ w_i \cdot \ln(f_s \cdot \mathscr{F}_s(m_i, t_i, \Omega_i) + f_s \cdot f_{B^0} \cdot \mathscr{F}_{B^0}(m_i, t_i, \Omega_i) + (1 - f_s \cdot (1 + f_{B^0})) \mathscr{F}_{\mathrm{bkg}}(m_i, t_i, \Omega_i)) \}$$

$$\mathscr{F}_s(m_i, t_i, \Omega_i, P(B|Q)) = P_s(m_i|\sigma_{m_i}) \cdot P_s(\sigma_{m_i}) \cdot P_s(\Omega_i, t_i, P(B|Q)|\sigma_{t_i}) \cdot P_s(\sigma_{t_i}) \cdot P_s(P(B|Q)) \cdot A(\Omega_i, p_{\mathrm{T}i}) \cdot P_s(p_{\mathrm{T}i})$$

The joint distribution for the decay time t and the transversity angles Ω for the $B_s \to J/\psi\phi$ decay is given by the differential decay rate

$$\frac{d^4\Gamma}{dt\, d\Omega} = \sum_{k=1}^{10} \mathscr{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \phi_T)$$

where $O^{(k)}(t)$ are the time-dependent amplitudes and $g^{(k)}(\theta_T, \psi_T, \phi_T)$ are the angular functions

New Physics Searches in Heavy Flavours

$B_s \to J/\psi\phi$ time-dependent amplitudes and angular functions

k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \phi_T)$
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\sin^2\psi_T\sin^2\theta_T$
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_\parallel$ $\left[(1+\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1-\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \pm 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$-\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$
5	$\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_L^{(s)}t} - e^{-\Gamma_H^{(s)}t})\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin(\delta_\perp-\delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp-\delta_\parallel)\cos\phi_s\sin(\Delta m_s t))]$	$\sin^2\psi_T\sin 2\theta_T\sin\phi_T$
6	$\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert[\frac{1}{2}(e^{-\Gamma_L^{(s)}t} - e^{-\Gamma_H^{(s)}t})\cos\delta_\perp\sin\phi_s$ $\pm e^{-\Gamma_s t}(\sin\delta_\perp\cos(\Delta m_s t) - \cos\delta_\perp\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\phi_T$
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{2}{3}\left(1-\sin\theta_T\cos^2\phi_T\right)$
8	$\lvert A_S\rvert\lvert A_\parallel(0)\rvert[\frac{1}{2}(e^{-\Gamma_L^{(s)}t} - e^{-\Gamma_H^{(s)}t})\sin(\delta_\parallel-\delta_S)\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos(\delta_\parallel-\delta_S)\cos(\Delta m_s t) - \sin(\delta_\parallel-\delta_S)\cos\phi_s\sin(\Delta m_s t))]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$
9	$\frac{1}{2}\lvert A_S\rvert\lvert A_\perp(0)\rvert\sin(\delta_\perp-\delta_S)$ $\left[(1-\cos\phi_s)\,e^{-\Gamma_L^{(s)}t} + (1+\cos\phi_s)\,e^{-\Gamma_H^{(s)}t} \mp 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s\right]$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$
10	$\lvert A_0(0)\rvert\lvert A_S(0)\rvert[\frac{1}{2}(e^{-\Gamma_H^{(s)}t} - e^{-\Gamma_L^{(s)}t})\sin\delta_S\sin\phi_s$ $\pm e^{-\Gamma_s t}(\cos\delta_S\cos(\Delta m_s t) + \sin\delta_S\cos\phi_s\sin(\Delta m_s t))]$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\phi_T\right)$